PIER Energy-Related Environmental Research
Environmental Impacts of Energy Generation, Distribution and Use

Evaluating Past and Improving Present and Future Measurements of Black Carbon Particles in the Atmosphere

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The Issue

In California, air pollution levels for fine particulate matter persistently exceed air quality standards in 12 counties reaching from the central to the southern part of the state. Fine particles in the air are a public health concern because they are small enough to be inhaled and deposited directly in the lungs, where they can cause asthma and other health problems. One common type of fine particulate, the soot produced from the combustion of diesel fuel, is considered a toxic air contaminant in California.[1] In addition to posing a health risk, diesel soot contributes to climate change. The black core of the soot, known as black carbon (BC), strongly absorbs sunlight and causes about as much global warming as the greenhouse gas methane.[2] In addition, sunlight absorption by BC is believed to influence regional climate by altering the hydrologic cycle, reducing cloudiness, and melting snow and ice.[3,4,5]

Although emissions from power plants represent a small source of BC soot in California, the trend toward distributed energy resources in California will likely continue. Distributed energy resource equipment includes microturbines, conventional combustion turbine generators, and reciprocating engines, all of which may run on diesel fuel. Also, a portion of the backup utility generators used during power outages in California is diesel fueled.

Concern about the public health and climate effects of BC soot has prompted scientists and regulatory agencies to develop emission inventories, determine emission trends, and better understand the atmospheric chemistry and physics of BC. These efforts require a method for

[1] California Air Resources Board (CARB). "Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles." October 2000. Available at www.arb.ca.gov/diesel/documents/rrpapp.htm.

[2] Jacobson, M. Z. Strong Radiative Heating due to the Mixing State of Black Carbon in Atmospheric Aerosols. *Nature* 409: 695–697. 2001.

[3] Ackerman, A. S., O. B. Toon, D. E. Stevens, A. J. Heymsfield, V. Ramanathan, and E. J. Welton. "Reduction of tropical cloudiness by soot." *Science* 288: 1042–1047. 2000.

[4] Menon, S., J. Hansen, L. Nazarenko, and Y. F. Luo. Climate effects of black carbon aerosols in China and India. *Science* 297: 2250–2253. 2002.

[5] Hansen, J., and L. Nazarenko. "Soot climate forcing via snow and ice albedos." *Proc. Natl. Acad. Sci.* 101: 423–428. 2004.

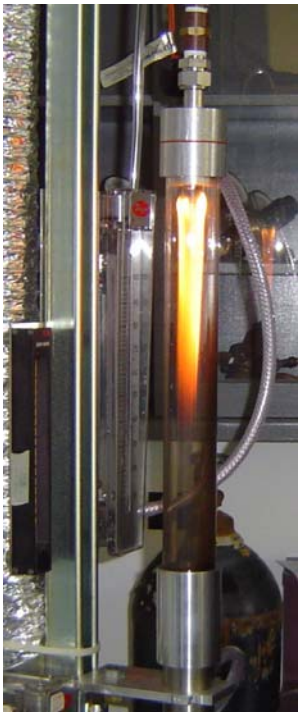
measuring BC concentrations accurately. It is widely recognized, however, that measurements of BC are highly uncertain. A growing body of scientific evidence, including preliminary work by the research team, suggests that the calibration of the aethalometer—a widely used instrument for measuring BC concentrations—is overly simplified and results in inaccurate measurements of BC concentration. Moreover, BC measurements have been made only recently, so any retrospective analysis of BC air pollution must rely on proxy data that can be related to modern BC measurements.

Project Description

This project, funded by PIER's Environmental Exploratory Grants Program, aimed to improve the certainty of BC measurements by evaluating aethalometer performance. The aethalometer filters particles from the air and estimates the amount of BC in the particles by measuring the amount of light absorbed by the filtered particles. The instrument is similar to another that was used extensively in California to quantify particulate matter air pollution in terms of coefficient of haze (COH).

The project evaluated aethalometer accuracy using a specialized combustion apparatus developed at Lawrence Berkeley National Laboratory—an inverted diffusion flame that generates controllable amounts of BC particles. As in a diesel engine, BC forms in the fuel-rich region of the flame. Laboratory experiments subjected the aethalometer and COH instruments to known amounts of BC and to BC mixed with other constituents common to atmospheric particles, such as salt.

Lab results were compared with aethalometer performance in a diesel engine exhaust-exposure chamber and in the Caldecott tunnel, a roadway (connecting Alameda and Contra Costa counties) that is heavily traveled by light-duty vehicles and diesel trucks.



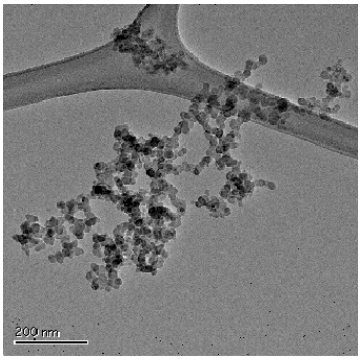


Photo courtesy Randy VanderWal, NASA Glen Research Center

This image of soot, obtained with high-resolution transmission electron microscopy, reveals its highly agglomerated structure. The soot was generated at Lawrence Berkeley National Laboratory using the inverted diffusion flame shown here.

In addition to assessing the accuracy of BC measurements made with the aethalometer, the project also related modern measurements of BC to historical measurements of COH and used the California record of COH to estimate the past history of BC in the atmosphere. Laboratory experiments and archived records of BC and COH concentrations measured at two locations were analyzed to determine the relationship between contemporary BC and historical COH measurements. BC trends in the San Francisco Bay Area were estimated based on COH measurements made at a large number of sites from the mid-1960s to the present.

PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Providing safe energy.** More-accurate BC measurements will help epidemiologists and climate change scientists understand how BC soot affects public health and the environment.

- **Providing environmentally sound energy.** In addition to the direct effects of BC on climate and air quality, light extinction by BC impacts the chemistry that forms other air pollutants—including ground-level ozone, a pervasive air pollutant and potent greenhouse gas. Moreover, temporally and spatially resolved BC concentrations are useful for examining how air quality and aerosol climate forcing have been influenced by changes in energy technology, fuel consumption, and emission control strategies. Such information will provide regulators and decision makers with a better foundation for planning the state's future energy supply.

Results

Laboratory and field results indicated that temporally resolved BC concentrations measured with an aethalometer may be inaccurate because this instrument's response to BC diminishes as its sampling filter becomes darkened with soot. The project developed a modification of the manufacturer's calibration, which is recommended when the aethalometer is used near BC sources. Away from the direct influence of BC sources, the predominance of light-scattering aerosols (e.g., sulfates, nitrates, organics) minimizes the filter-induced measurement error.

Archived COH measurements were used to estimate past BC concentrations in the San Francisco Bay Area, where diesel vehicles are the dominant BC source. Estimated BC concentrations decreased by a factor of three from the late 1960s to the early 2000s despite the six-fold increase in diesel fuel consumption in California. The decrease in ambient concentrations is attributed to pollutant abatement policies. Diesel emission factors, based on estimated BC concentrations and fuel consumption data, decreased from more than ten to less than one gram of BC emitted per kilogram of fuel consumed over this period.

Continued evaluation of BC measurements focusing on newly emerging techniques is recommended, as is research to understand how climate-relevant optical properties of BC change when it combines in the atmosphere with other aerosol species. Extension of the current evaluation of historical BC concentrations to other air basins in California is recommended and would be aided by new collocated measurements of COH and BC. Establishment of a statewide BC monitoring network is recommended for tracking BC concentrations in the future.

Final Report

The final report for this project can be downloaded from the Energy Commission's website at www.energy.ca.gov/2007publications/ CEC-500-2007-042/CEC-500-2007-042.pdf.

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